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HUMAN PHYSIOLOGICAL RESPONSE TO
EXTREMITY AND BODY COOLING

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ARCTIC AEROMEDICAL LABORATORY
FORT WAINWRIGHT
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**Department of Protective Equipment
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**Technical Report 61-26
Project 8242-2**

**ALASKAN AIR COMMAND
ARCTIC AEROMEDICAL LABORATORY
FORT WAINWRIGHT
ALASKA
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ABSTRACT

A study of the critical regions of the body which must be protected with insulation against a cold stress made it necessary to ascertain the response of the extremities as opposed to the rest of the body when subjected to a cold environment. Five subjects at rest were exposed to a temperature of -18°C in an environmental chamber while wearing three different clothing configurations: 1) Thermistor underwear, 2) approximately 10 clo insulation on the body with the exception of only the hands and feet, which were left bare, and 3) approximately 10 clo insulation on the extremities with the rest of the body bare or covered with the thermistor underwear.

The average subject tolerance time -- defined as when any skin site reached 4° or 0°C -- while wearing only the thermistor underwear and having the body heavily insulated while the extremities were bare was 8 minutes. The average subject tolerance time with the extremities heavily insulated and wearing only the thermistor underwear was 83 minutes. The results illustrate the temperature sensitivity of the extremities and their tolerance limitations in extreme cold environments. A large quantity of insulation on the body (excluding the extremities) does not ameliorate tolerance despite a warm core temperature. If the extremities are adequately protected, however, the rest of the body with the possible exception of the ears is able to tolerate a low environmental temperature for extended periods of time.

HUMAN PHYSIOLOGICAL RESPONSE TO EXTREMITY AND BODY COOLING*

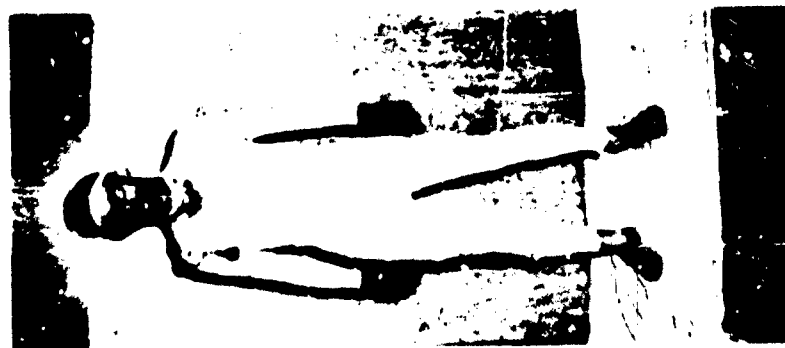
Extremity protection in cold environments is of primary importance when humans are subjected to a cold stress. Carlson and Thurn (1959) have prepared a selected bibliography with abstracts pertaining to this area of interest. To determine the critical regions of the body which must be protected with insulation against a cold stress, it is necessary to obtain quantitative information on the hands and feet when exposed to a cold environment. A simple experimental program was designed which would not only determine the response of the extremities in cold temperatures but would also give an insight into ways of protecting these areas of the body. Rapaport, *et al.*, (1949) and Spealman (1945) have found at ambient temperatures as low as -30°F that regulation of the blood flow to the hands and feet is primarily determined by the thermal state of the body as a whole. The experimental program was designed to verify these results.

METHODS

Five subjects were exposed to a temperature of 0°F in an environmental chamber while wearing the three different clothing assemblies listed in Table I and shown in Figure 1. Air movement drastically affects the tolerance patterns even at minimal flows. Therefore, air movement was reduced to < 5 feet/minute for these experiments. One clothing assembly was considered minimal (Assembly I), while the other two assemblies had over 10 clo (on just the extremities, or covering the body and excluding just the extremities). One additional experiment was conducted with the subject wearing Assembly I to determine the effect of gloves and socks on extremity temperature. In this experiment, glove and sock were worn on one hand and foot while the other hand and foot were left bare for comparative purposes.

Five skin temperatures were recorded from each hand and foot in all experiments. In addition, representative skin temperatures were measured on the body, and the internal body temperature was determined. The skin

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Assembly 1



Assembly 2



Assembly 3

Figure 1. Three experimental clothing assemblies.

TABLE I

Clothing Worn	Estimated Clo Value
<hr/>	
Assembly 1	
Thermistor Underwear	0.3 clo
<hr/>	
Assembly 2	
Thermistor Underwear	0.3 clo on body
One pillow on each hand and foot	>10 clo on hands and feet
<hr/>	
Assembly 3	
Thermistor Underwear	
Four Sleeping Bags	10 clo except hands and feet
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temperatures of the hand (excluding the fingers) were averaged and are referred to as hand body temperature. The same procedure was used for the feet, and the term foot body temperature is used. Both hands and feet are averaged to present a single value.

The experimental procedure was to dress and instrument the subjects and to obtain control skin and rectal temperature readings of these subjects while sitting outside the chamber in a temperature environment of 75° F. The subject then walked into the chamber and sat at rest until tolerance was reached. Tolerance in this report is defined as the time when any skin site reached a temperature of 40° F. At Carlson's suggestion (1961), additional experiments were conducted in which the skin temperatures were allowed to drop to 32° F before terminating the experiment. This would afford additional time for any Lewis effect (cyclic vascular response) to occur. In this subsequent experimental series, five subjects instrumented as described above were subjected to a 0° F environment while wearing the heavy insulation on the body and leaving the extremities bare. The locations for the skin temperature measurements are shown in Figure 2.

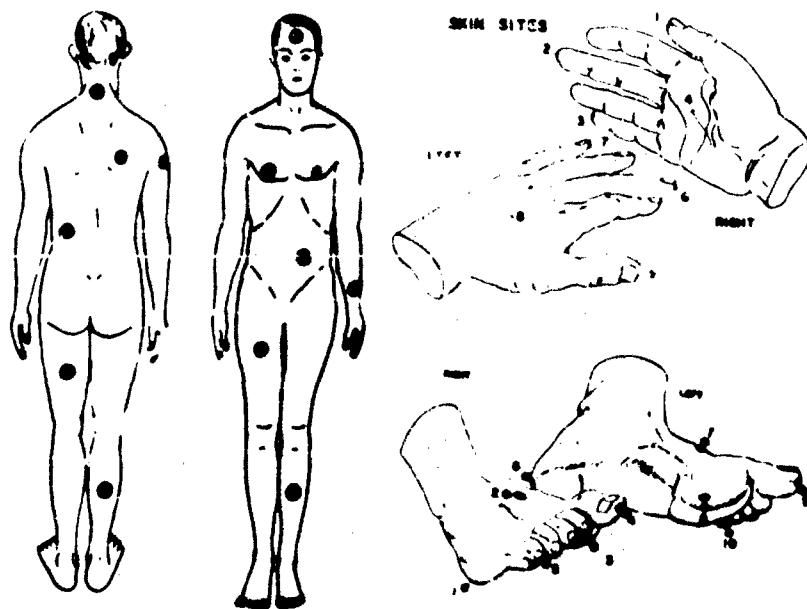


Figure 2. Body Locations of Skin Temperature Measurements.

The subcutaneous thermocouples were placed next to surface thermocouples on the middle finger and the big toe during the experiment where the bare hand and foot were compared with the insulated hand and foot.

RESULTS

The average times for the subjects to reach skin temperatures of 40°F while wearing only the thermistor underwear and while wearing heavy insulation on the body but with the extremities bare were identical (8 minutes). The average time for the subjects to reach 40°F temperatures having heavily insulated extremities with the rest of the body bare or covered by the thermistor underwear was 83 minutes. In the series of experiments where skin temperatures were allowed to fall to 32°F or less, the average tolerance time of four subjects was 14 minutes. One subject had a strong vascular response or Lewis effect which he maintained for 60 minutes before the tolerance point was reached.

The skin and rectal temperatures were most effective in reflecting the body's physiological response to the stress, and their responses are shown in Figure 3. The terminal point was a skin temperature of 40°F . The base of the arrow denotes the starting temperature level, and the head of the arrow shows the final temperature levels reached. Each arrow represents an average value for five subjects. Figure 4 represents only one experiment, in which the subject wore only thermistor underwear with a sock on one foot and a glove on one hand. The other hand and foot were left bare. The subcutaneous and surface thermocouple values for each extremity are graphed.

DISCUSSION

The experimental results illustrate the temperature sensitivity of the extremities, and their tolerance in extreme cold environments is limited. At this temperature, the vasculature does not appear to be able to compensate for the environmental stress in the majority of individuals, even though finger or toe temperatures were allowed to fall to 31°F with no apparent Lewis response. The one exception, which enabled a subject to

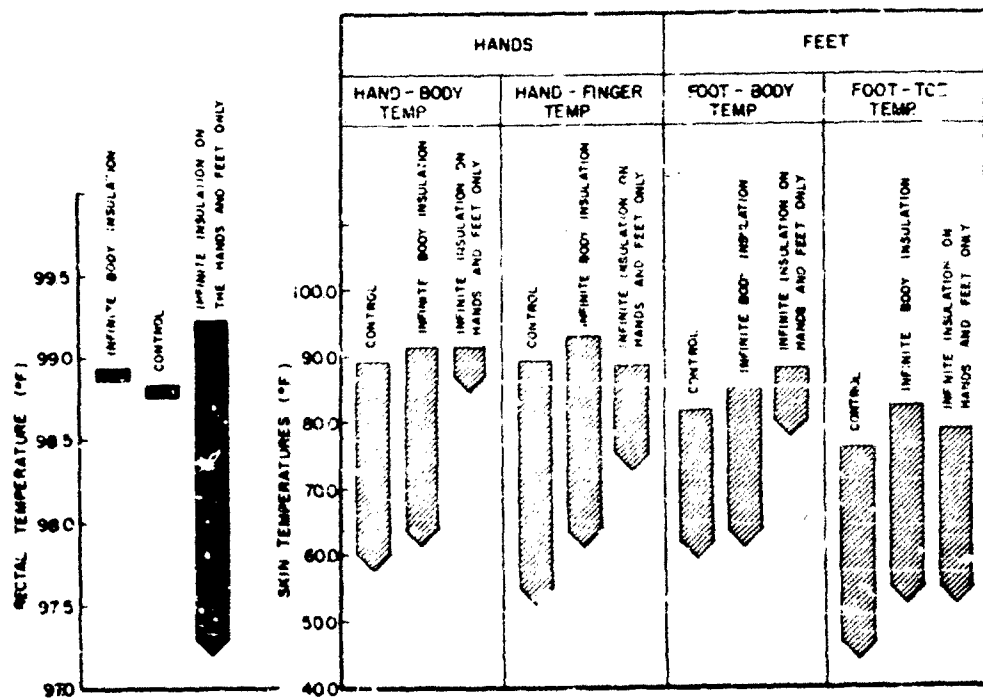


Figure 5. Average rectal and skin temperature responses to environmental exposures.

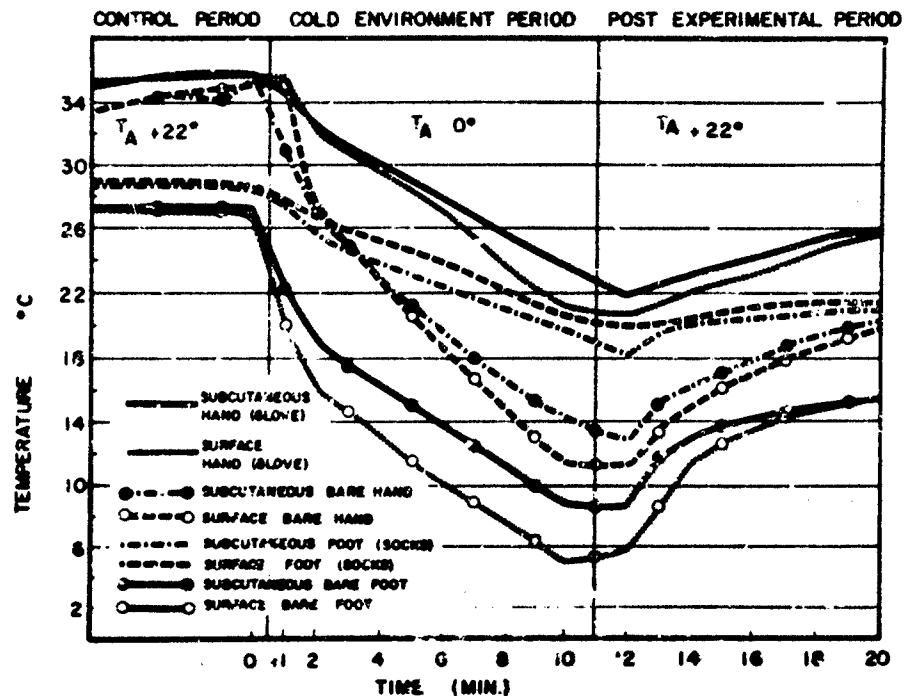


Figure 4. Skin and subcutaneous temperatures of the extremities.

withstand the cold stress for 60 minutes, illustrates the variability of the species and should not be ignored.

A large quantity of insulation on the body excluding the extremities does not ameliorate tolerance in most persons despite a warm core temperature. The finding of Rapaport, et al., (1949) -- that if heat was supplied to the body adequate to maintain thermal equilibrium, the average temperature of the hands and feet was maintained above 70° F -- is not verified by this data. In view of the short time-duration of our experiments and skin and core temperatures, there was no change in the body's thermal equilibrium. Therefore, it would appear that, due to the intense sensory input, immediate vasoconstriction occurs despite body insulation if the extremities are exposed to this low ambient temperature. The short time period does not appear to allow the central mechanism to initiate preventive vascular changes which would increase tolerance to this cold stress.

A driving thermal gradient from the warm body to the extremities, therefore, does not prevent vasoconstriction from occurring under these experimental conditions. If the extremities are over-protected, however, the rest of the body (with the possible exception of the ears) is able to tolerate a low environmental temperature for extended periods of time. Heavy shivering occurred immediately and persisted for the duration of the exposures, which undoubtedly delayed the rate of body cooling. The final skin and rectal temperatures in Figure 3 merely reflect this rate of body cooling with time. With more moderate temperature stress, the tolerance time would be extended, but the same difference between the three clothing assemblies would be predicted.

The addition of insulation on an extremity reduces the rate of skin and core cooling, which is seen in Figure 4. The surface thermocouple reading very accurately reflects temperature changes when compared with the subcutaneous temperature. The anomaly that is seen in the foot covered by a sock, where the thermocouple temperature was above the subcutaneous temperature, may be due to location and vasculature. Tolerance criteria in all experiments were reached by the feet before the hands, which may be explained by the fact that the feet are normally covered by socks and shoes whereas the hands normally experience cold temperatures and the vasculature may have undergone adaptive changes. Exercise would undoubtedly increase tolerance time in all situations.

CONCLUSIONS

1. Hands and feet are very temperature-sensitive, and at extreme temperatures tolerance time is limited.
2. A heavily-insulated body does not enhance tolerance of the extremities for most persons under these experimental conditions. This implies an intense vasoconstriction of the vasculature of the extremities due to local response of peripheral receptors.
3. If the extremities are adequately protected, the rest of the body (with the possible exception of the ears) is able to tolerate a low environmental temperature for long periods of time.

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